Biaxial Vibration Measurement Using Piezoelectric Paint Sensors

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Introduction

Piezoelectric paint is a thick-film material that may be used to form thick-film vibration sensors by spraying directly onto a structure. Like any paint it is comprised of two components: a pigment and a vehicle. In a conventional paint the pigment gives the paint its colour. This is replaced by finely powdered PZT (lead-zirconate-titanate), a piezoelectric ceramic. The vehicle is a liquid that holds the pigment in suspension while it is applied to the surface, and then cures to form a solid polymer matrix, locking the particles in place.

Piezoelectric paint vibration sensors are made by sandwiching a film of piezoelectric paint between two electrodes. Deformation of the film generates a charge on the electrodes which may be measured and hence used to determine strain in the paint film. Piezoelectric paint thick-film sensors is described fully in [1].

These sensors are most easily used to measure strain in the direction normal to the film, and hence as dynamic pressure sensors. When used as vibration sensors it is the strain parallel to the surface that is measured, but unlike a resistance strain gauge there is no orientation of the sensor, so it is not obvious what exactly is being measured when the sensor is subject to biaxial strain. It was suggested that the measured charge is proportional to the sum of principal strains, and this paper describes a series of experiments by which this hypothesis is proven.

Experimental Facility

An experimental rig comprising a cross test piece could be loaded in three independent bending modes as shown in Figure 1: (a) with the two arms bent in the same sense, (b) with one arm of the cross bent and the other left free, and (c) with the two arms bent oppositely. At the crossing point a piezoelectric paint sensor was deposited on one face and a three gauge strain rosette on the other. Three different arrangements of principal strains could thus be generated in the sensors. Furthermore, the magnitudes of these principal strains could be measured independently using the strain gauges and compared with the piezoelectric paint sensor measurements, the only assumption being that the strain on one face was equal and opposite to that on the opposite face.

The piezoelectric paint sensor was characterised by measuring transient vibration. The cross was loaded suddenly with a constant force (a dead weight) in one of the three loading modes and allowed to vibrate freely. Signals from the three strain gauges were obtained using a bridge amplifier in quarter bridge mode and recorded digitally. From these data principal strains were calculated in the usual way. The piezoelectric paint sensor output was conditioned using a good quality charge amplifier (Kistler 5011) and recorded simultaneously. The resonant frequency was approximately 27Hz and the sampling rate 1000 samples/s.

Results

Figure 2 shows the principal strains and piezoelectric paint sensor output for the first test (Figure 1a). The small difference between the principal strains is due to small asymmetries and is not significant since the true values are measured. The sum of the principal strains is thus also in phase and twice the magnitude of the individual principal strains. The paint sensor response is also in phase and decays with the principal strains.

These results are shown more conclusively in Figure 3, where the two measures are plotted against one another. All the data points, approximately 37 points per cycle, are plotted giving a heavy concentration of points around the final steady strain of $10^{-3}$, but also a significant number of data points near the extremity of the large amplitude early cycles. It is clear there is a nearly linear relationship between sum of principal strains and piezoelectric paint sensor output which is independent of magnitude and free of hysteresis.
Figures 4 and 5 show similar results for the second test (Figure 1b). The principal strain in the direction of the bent arm ($\varepsilon_1$) is large. The other ($\varepsilon_2$), in line with the free arm, is the complementary strain and so is smaller and in antiphase. The sum of the principal strains is thus smaller than $\varepsilon_1$ and in phase with it. The paint sensor signal is again in phase with the sum of principal strains. Figure 5 shows that the two are proportional with good linearity, little hysteresis and with the same slope, and hence sensitivity, as in Figure 3.

Figure 6 shows results for the third test (Figure 1c). The two principal strains are approximately equal and opposite and the piezoelectric paint sensor gives almost zero output.

Further results from these tests are given in [2].

**Conclusion**

It is shown that the output of piezoelectric paint thick-film vibration sensors under biaxial loading is proportional to the sum of principal strains

Furthermore, the paint sensors show good linearity up to a strains greater than 200µε.

**References**
